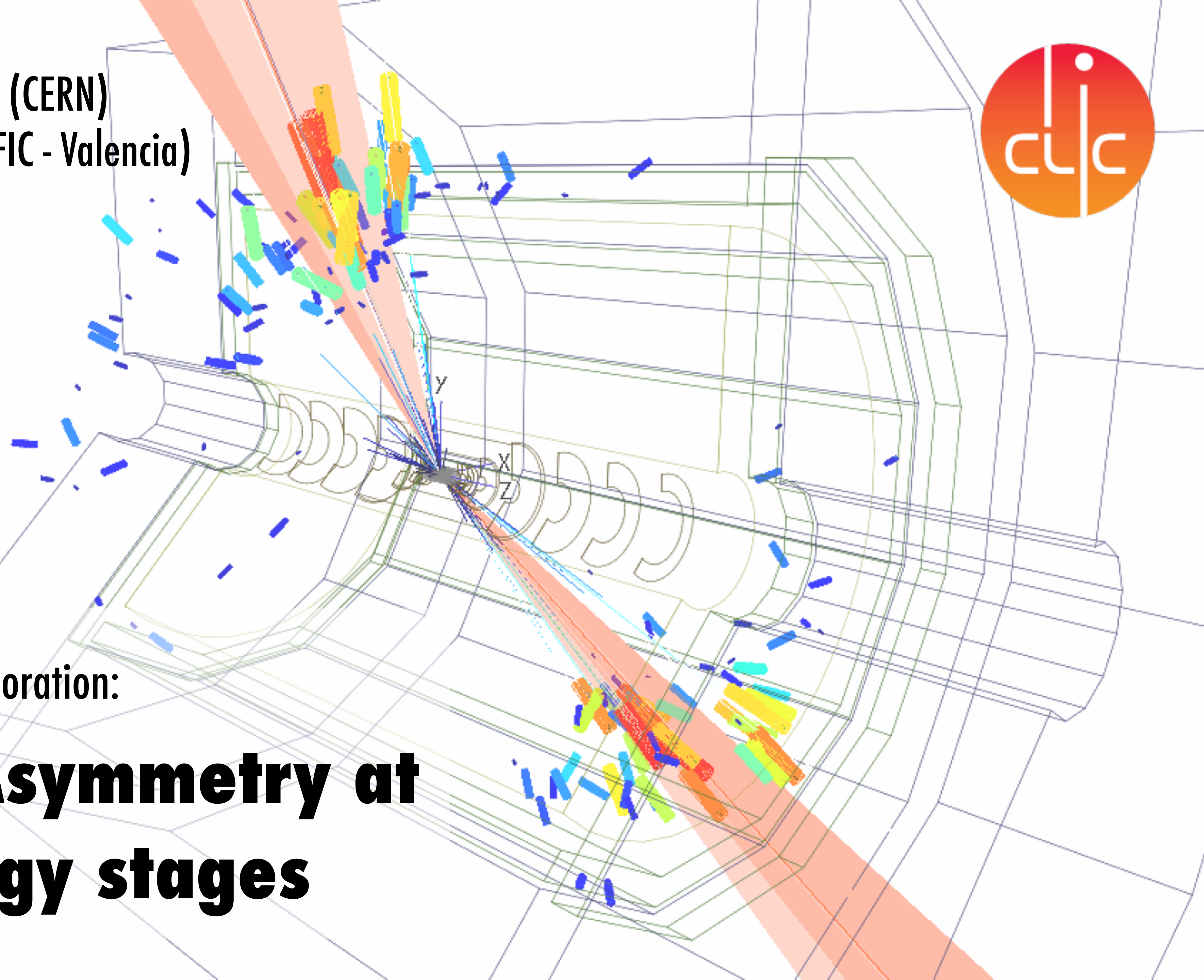


Philipp Roloff and Rickard Ström (CERN)
Martín Perelló and Marcel Vos (IFIC - Valencia)
CLIC Week, 8 March 2017

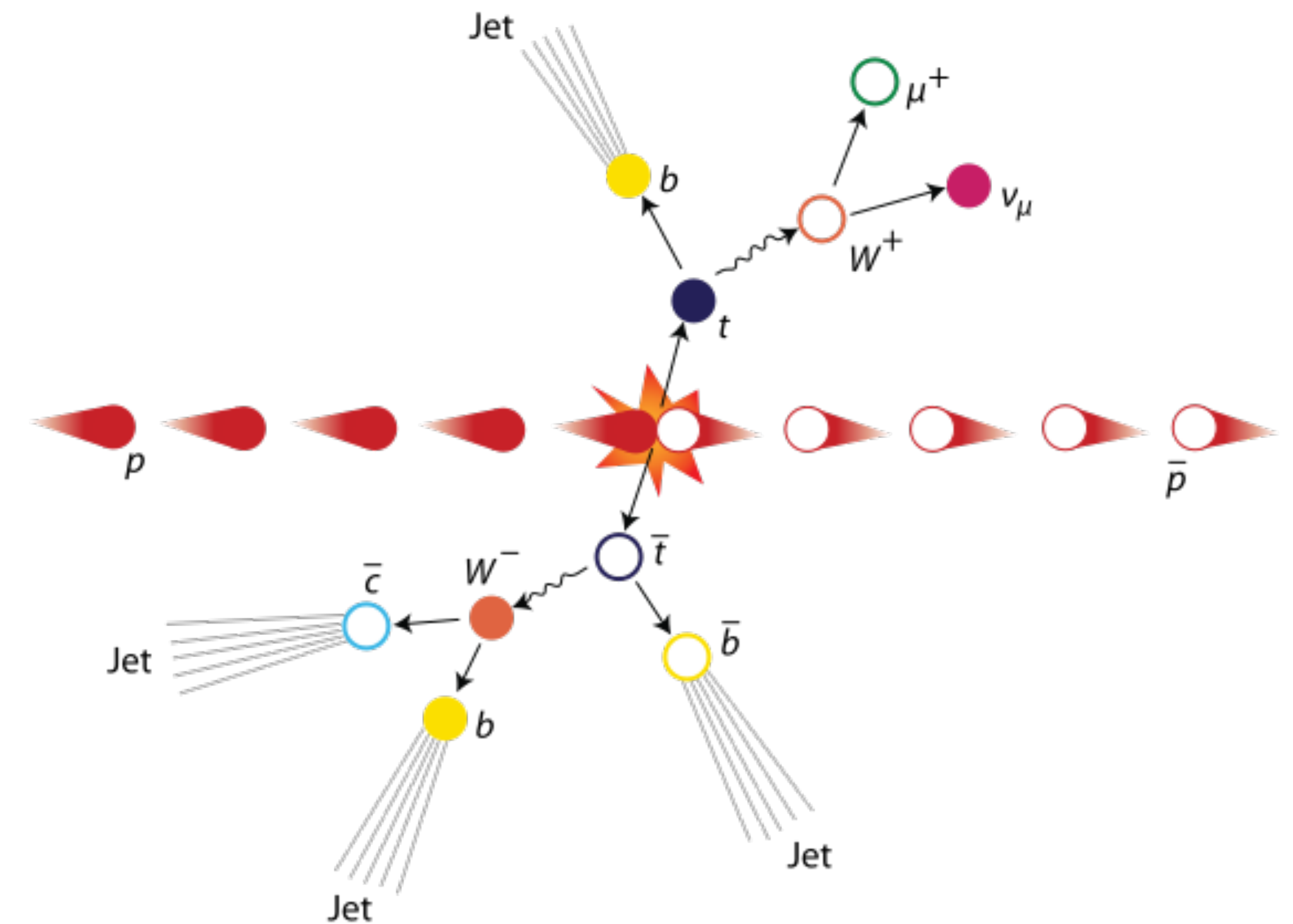


On behalf of the CLICdp Collaboration:

Towards Top Asymmetry at CLIC high-energy stages

- For $t\bar{t}$ production at high-energy CLIC operation - increased boost leads to separation between decay products
- Mass and couplings to Z and γ are among the main focuses of the initial stage of CLIC - plan to extend the top coupling study to higher energy stages
- Observables: cross-sections, forward-backward, left-right asymmetries, etc.
- Sub-percent precision on anomalous electroweak couplings yields sensitivity to new physics at scales well beyond the direct reach
- Interpretation: form-factors, effective operators

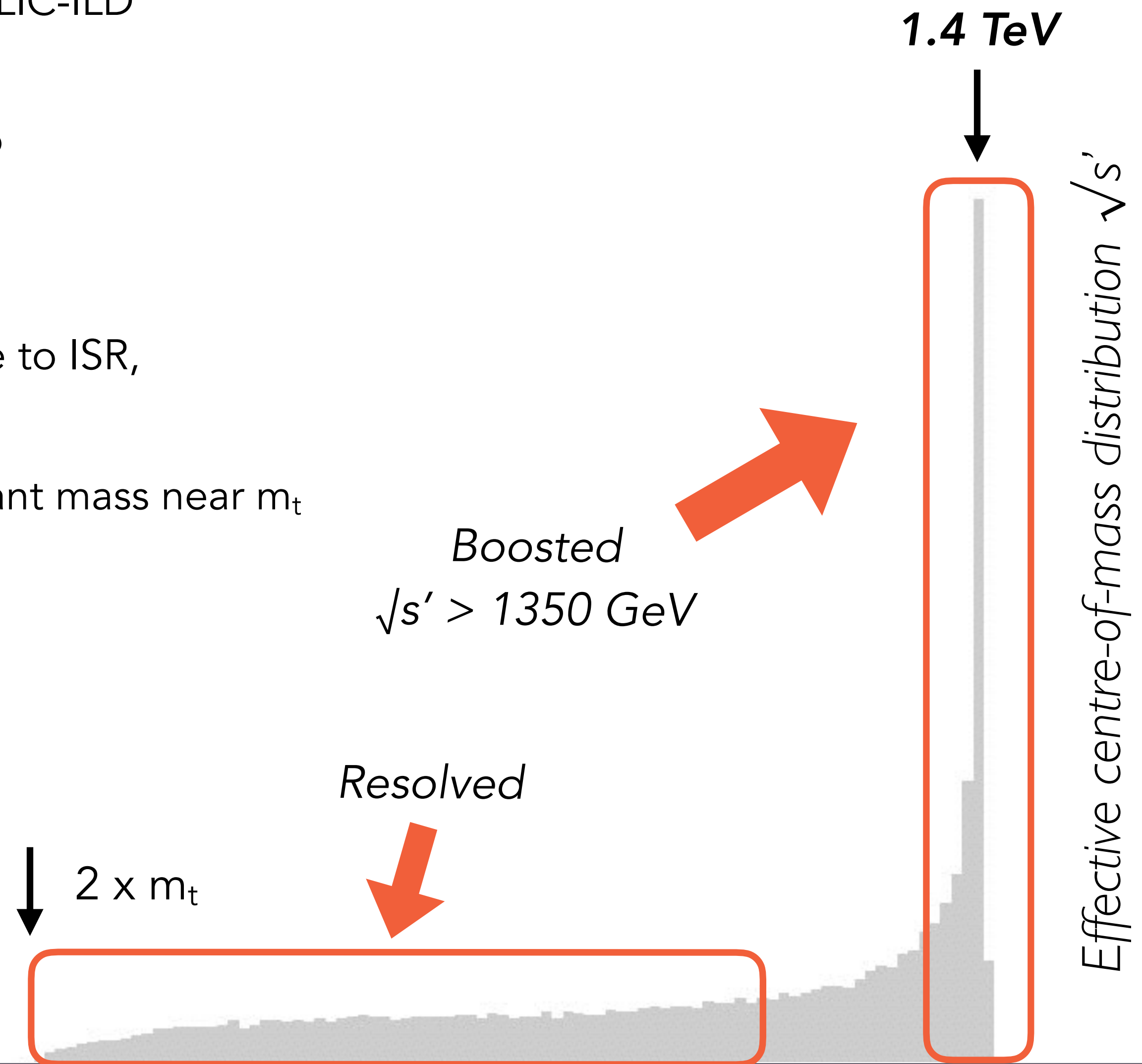
Signal definition:
 $e^+e^- \rightarrow t\bar{t} \xrightarrow{*} WbWb \rightarrow qqql\nu$



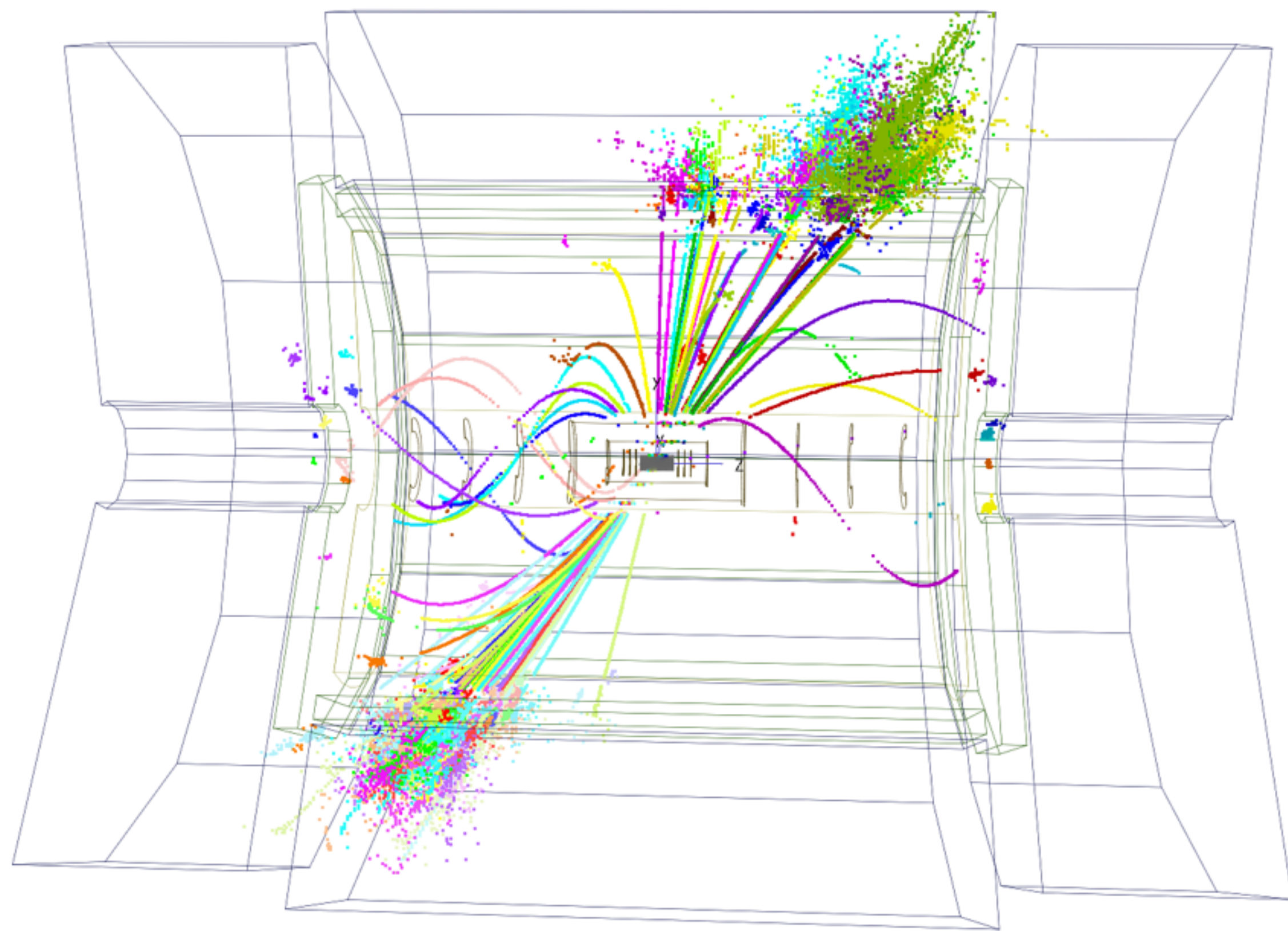
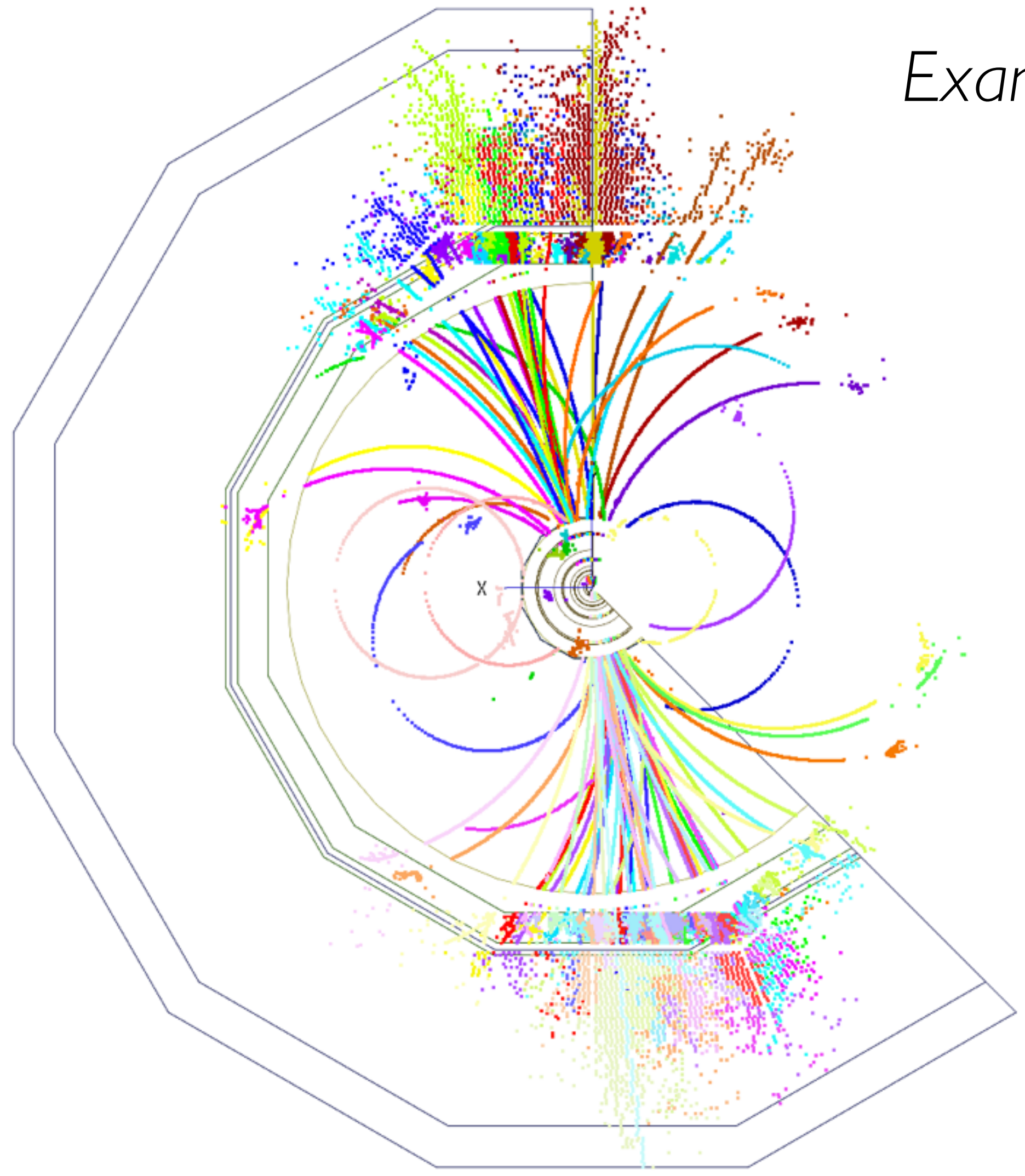
* + additional semi-leptonic channels where $t \rightarrow Wb$

Interpretation: 'Top quark couplings studies in electron-positron colliders at high energies' by Martin Perello Rosello

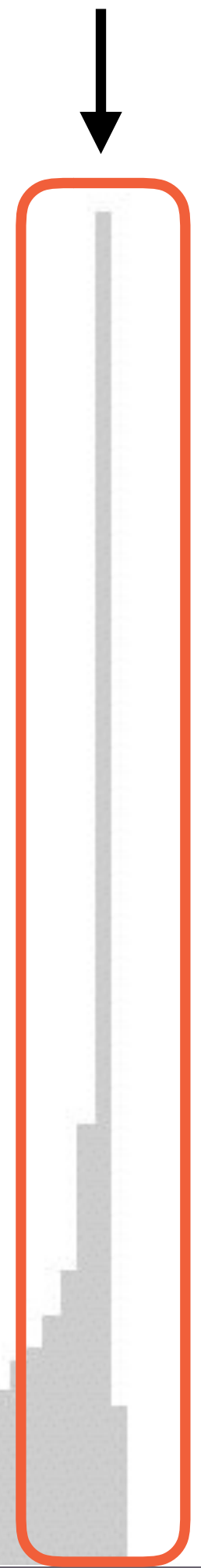
- Analysis concept studied at benchmark energy 1.4 TeV using CLIC-ILD
- Signal definition: semi-leptonic $t\bar{t}$ ($t\bar{t} \rightarrow q\bar{q}q\bar{q}l\nu$)
- Use lepton charge to reconstruct the charge of the top/anti-top
- *Resolved analysis*
 - Production near threshold (lower effective centre-of-mass due to ISR, beamstrahlung, luminosity spectrum)
 - Use b-tagging, search for W, or 3 jets with a combined invariant mass near m_t
- *Boosted analysis (large R-jets/fat-jets)*
 - Standard identification techniques may not work:
 - b-tagging difficult - tracks are crowded/unresolvable
 - W decay products not isolated from each other or b-jet
 - Idea: tag tops by identifying prongy structure - signature of a top decay



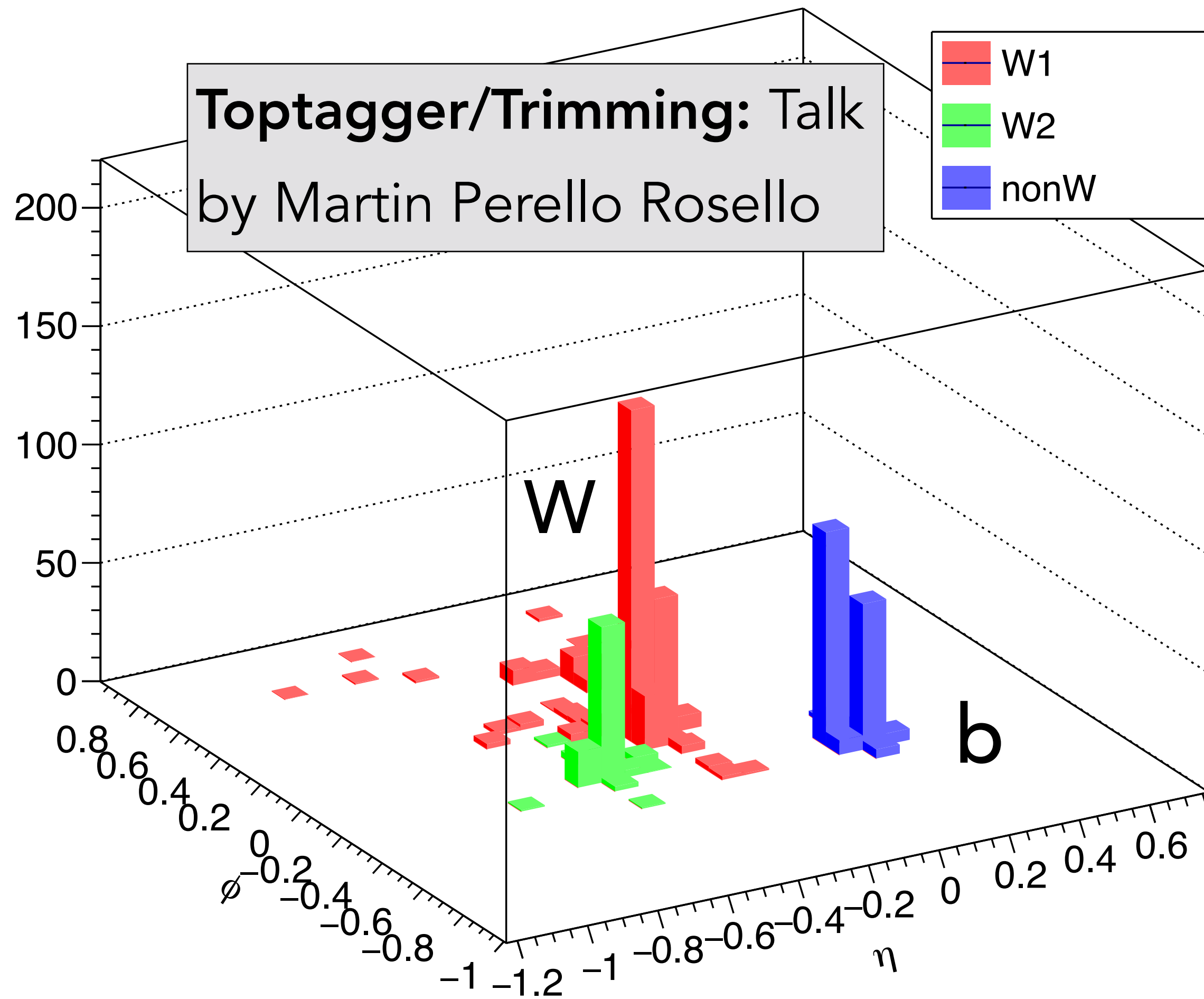
Example: boosted event topology



Boosted



Effective centre-of-mass distribution $\sqrt{s'}$



- *Technical cut: Boosted $\sqrt{s'} > 1350$ GeV at generation level (will be transferred to reco level)*
- *Analysis cuts:*
 - 1 isolated lepton (electron or muon), incl. cuts on track energy, impact parameter, calorimeter information, and cone isolation
 - 1 top tagged jet
 - VLC $(R, \beta, \gamma) = (1.5, 1, 1)$
 - $\delta_p = 0.05, \delta_r = 0.05$, [Kaplan et al.]
 - Using jet clustering on trimmed jets
 - ~53 % jet efficiency
 - Flavour tagging (e.g. sum of b-tags)
 - Exploit "missing" part (neutrino) (ongoing)

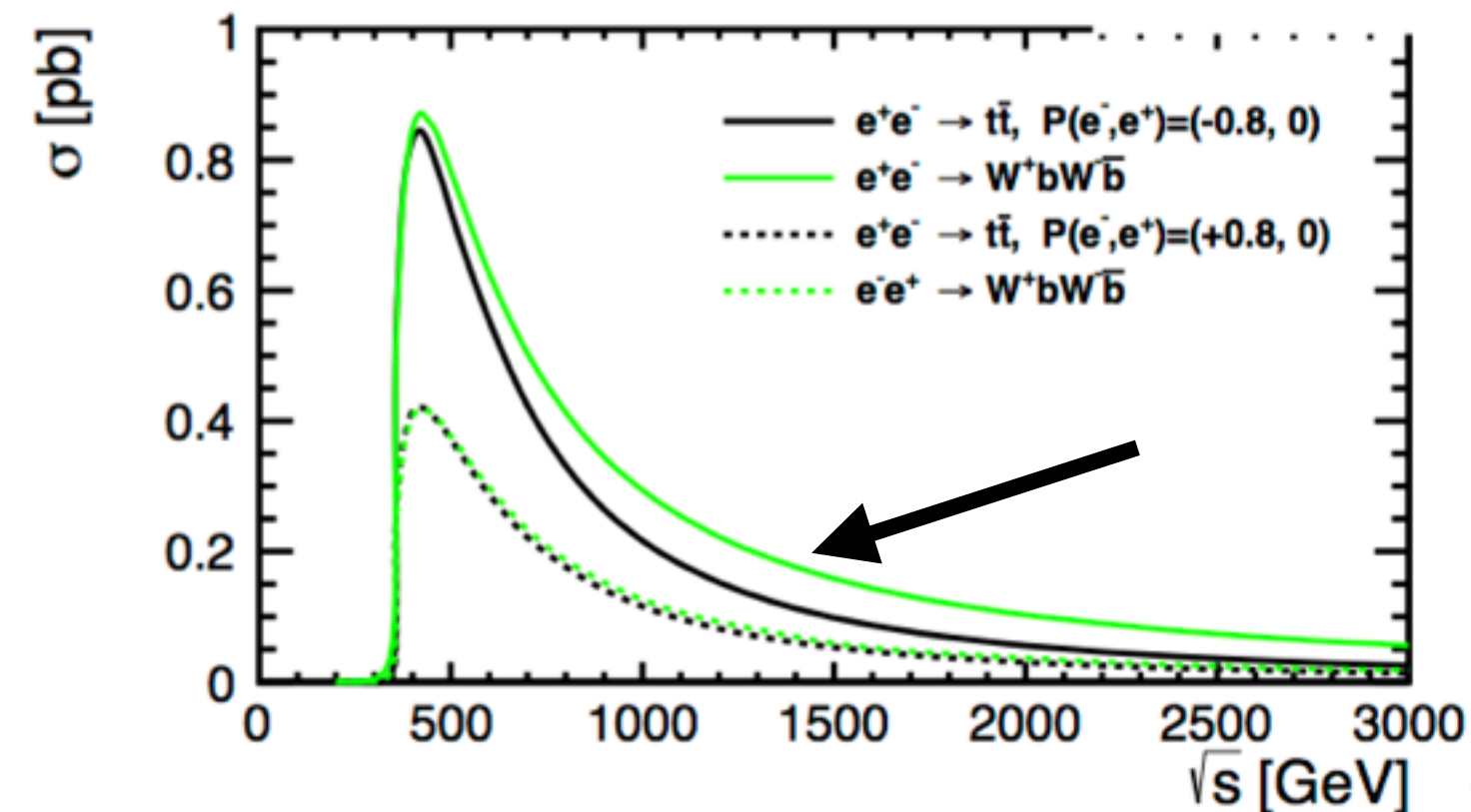
$P(e^-) = -80\%$ (similar construction for $+80\%$)

- **Signal definition**

- $e^+e^- \rightarrow qqqqlv$ (tt) (part of 6f samples)

- **Background definition**

- $e^+e^- \rightarrow qqqqlv$ (comp. to tt final states) (part of 6f samples + 5594/6191)
- $e^+e^- \rightarrow qqqqqq$ (tt) (part of 6f samples)
- $e^+e^- \rightarrow qqqqqq$ (comp. to tt final states) (part of 6f samples)
- $e^+e^- \rightarrow qq$ (2091)
- $e^+e^- \rightarrow qqvv$ (3243)
- $e^+e^- \rightarrow qqll$ (3246)
- $e^+e^- \rightarrow qqlv$ (3249)
- $e^+e^- \rightarrow qqqq$ (4034)
- $e^+e^- \rightarrow qqqqv$ (5527/6183)
- $e^+e^- \rightarrow qqqqll$ (5572)



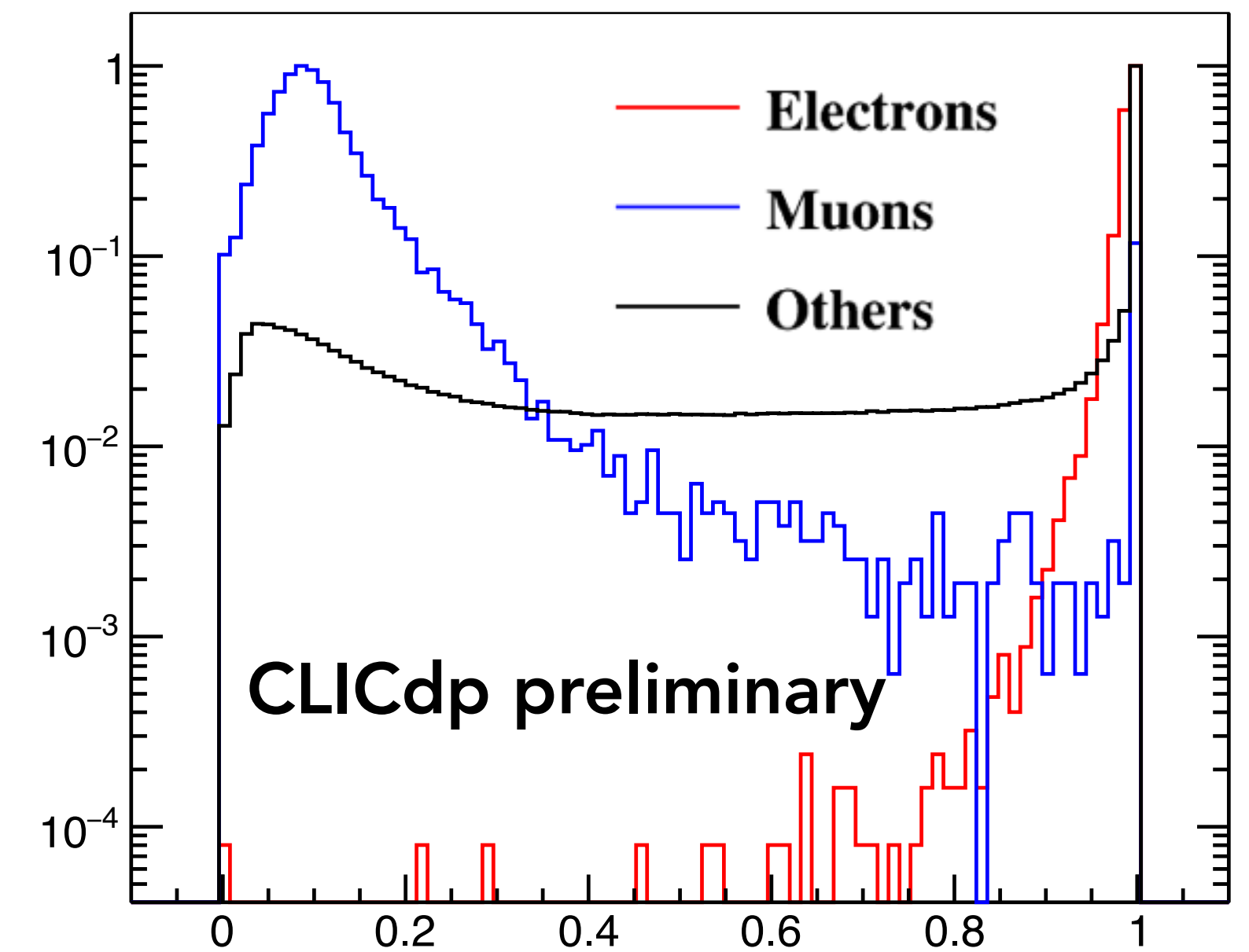
6 fermions final state samples

Type	ProdID	Events planned	Events produced	σ [fb]	Comments
ee -> yyveev	6586	15000	15600	7.91	
ee -> yyveyx	6589	50000	57600	31.9	NEW
ee -> yyxyev	6592	50000	61800	29.0	NEW
ee -> yyuyyc	6595	50000	50400	29.7	NEW
ee -> yycyyu	6598	50000	52200	29.7	NEW
ee -> dduyyu	6601	50000	76600	30.0	NEW
ee -> ssussu	6604	10000	11600	0.018	
ee -> ssubbu	6610	10000	11400	0.096	
ee -> bbubbu	6607	10000	12800	0.013	
ee -> ddcyyc	6613	10000	14400	1.82	
ee -> sscssc	6616	10000	11800	1.52	
ee -> sscbbc	6619	40000	58400	23.5	
ee -> bbcbbc	6622	10000	12000	0.013	
ee -> yyvelv	6625	20000	23800	10.8	
ee -> yyvlev	6628	20000	23600	9.82	
ee -> yyvllv	6631	30000	36400	15.6	
ee -> yyvlyx	6634	70000	91200	40.7	NEW
ee -> yyxylv	6637	70000	71800	40.7	NEW

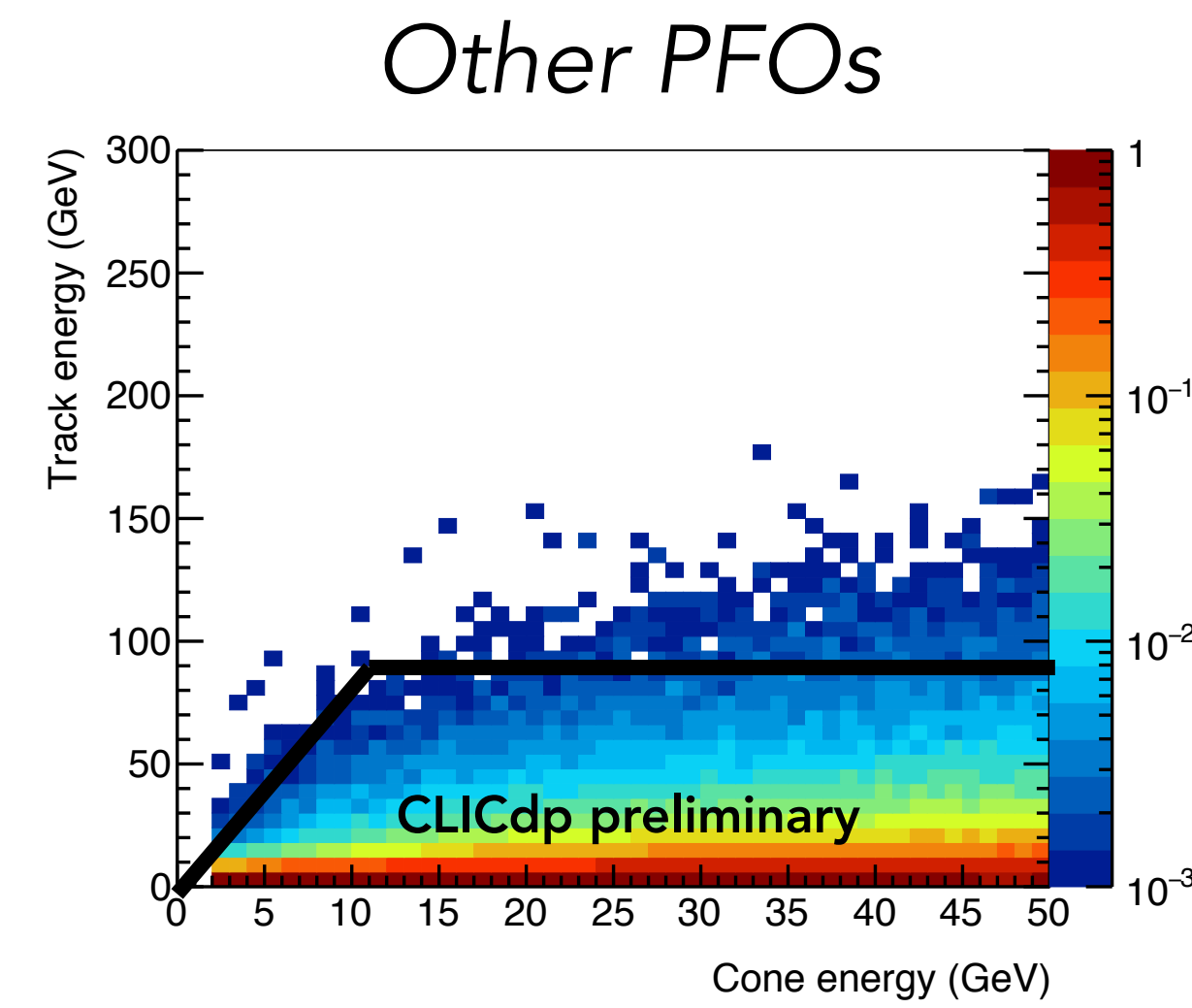
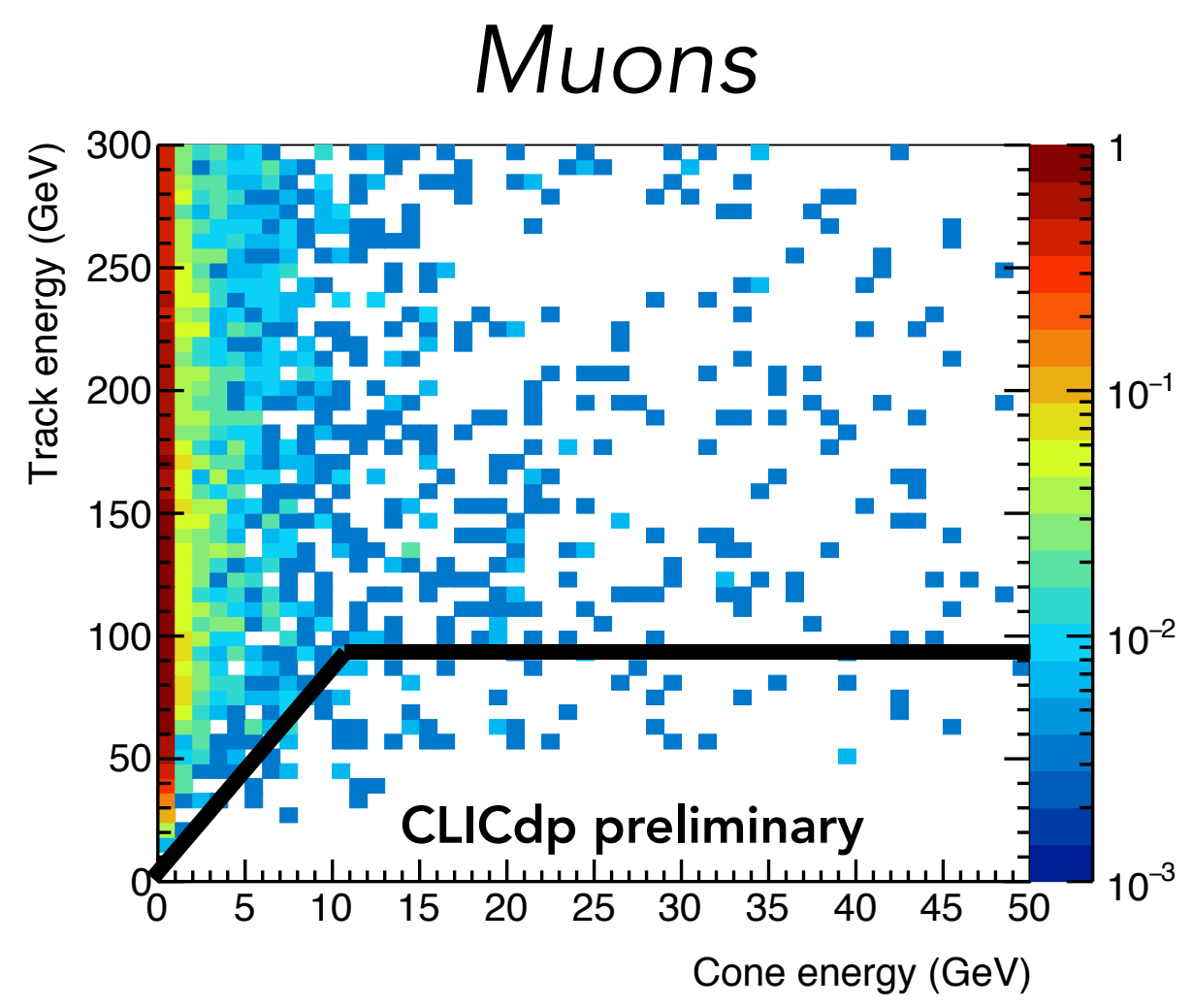
<https://twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForTopPhysics>

- Identify leptons (electron, muon) from the W^\pm decay
- Using Marlin processor: *IsolatedLeptonFinder*
 - Track energy (≥ 15 GeV)
 - Impact parameter ($R_0 \leq 0.1$ mm, $Z_0 \leq 0.05$ mm, $d_0 \leq 0.05$ mm)
 - Calorimeter energy deposition
 - Isolation information (cone $\sim 2.6^\circ$)
 - Results: muon: $\sim 92.5\%$ ($\sim 0\%$ fake), electron: $\sim 82\%$ ($\sim 0\%$ fake)

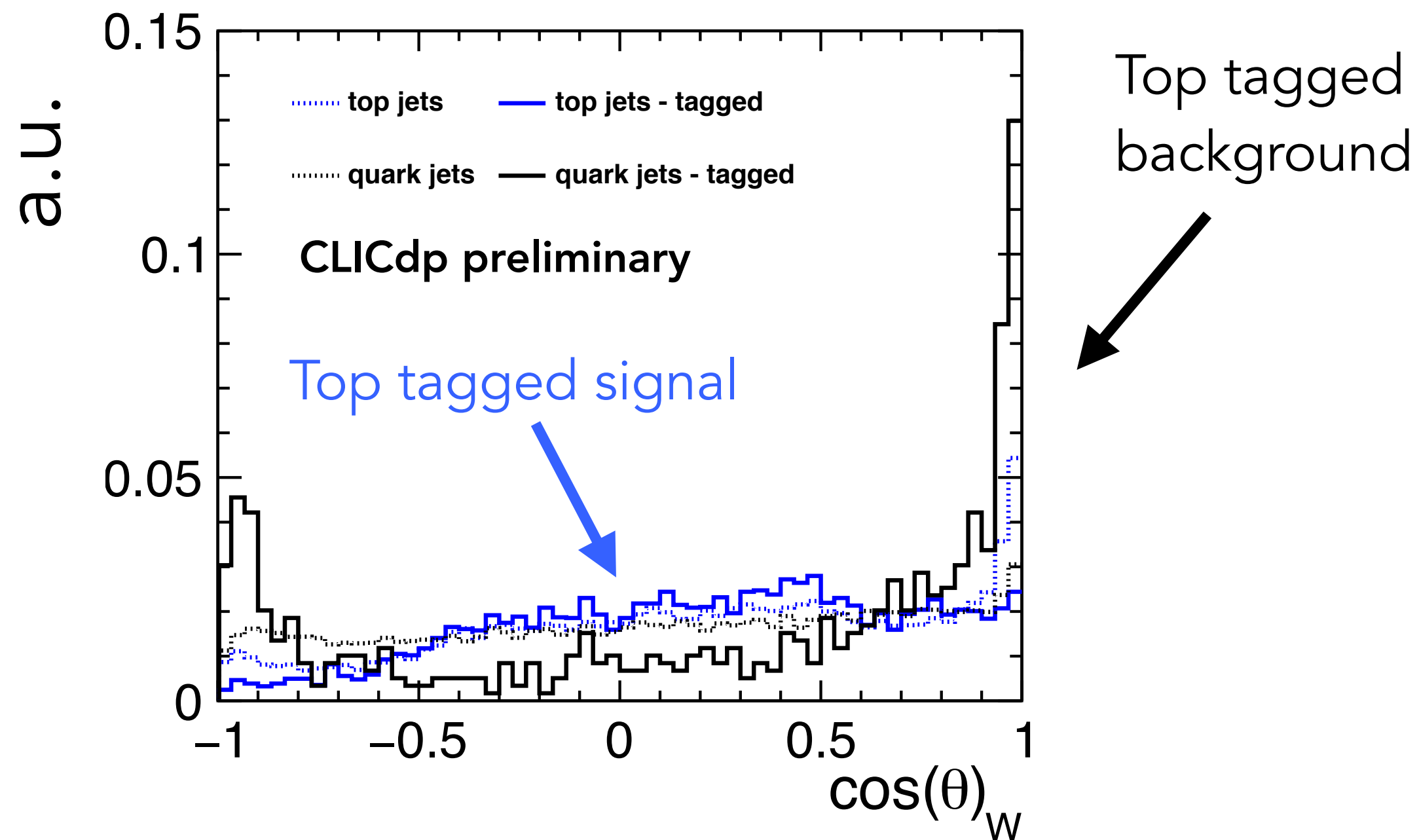
“Fraction of total CAL energy observed in the ECAL”



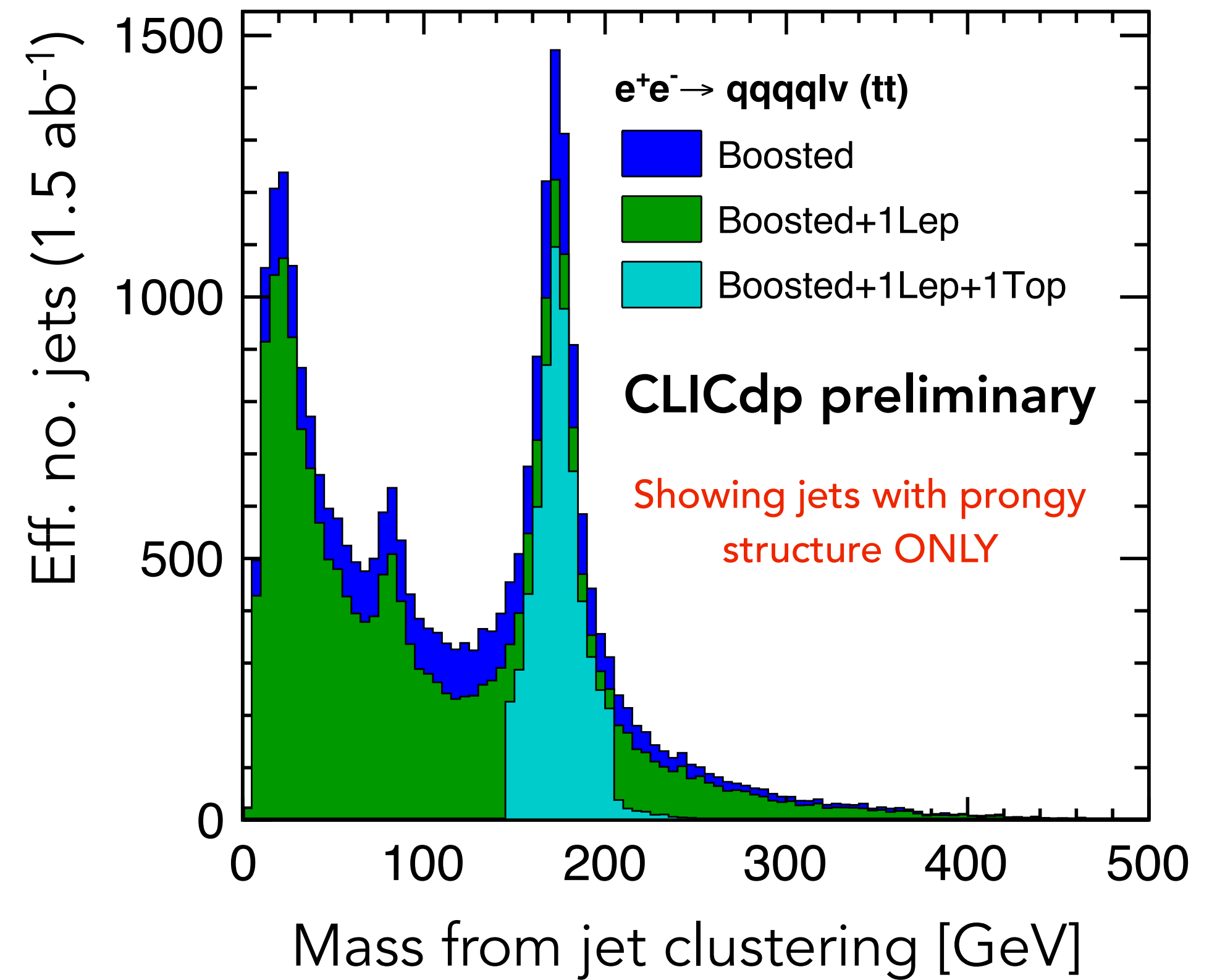
$$R_{\text{Cal}} = E_{\text{ECal}} / (E_{\text{ECal}} + E_{\text{HCal}})$$



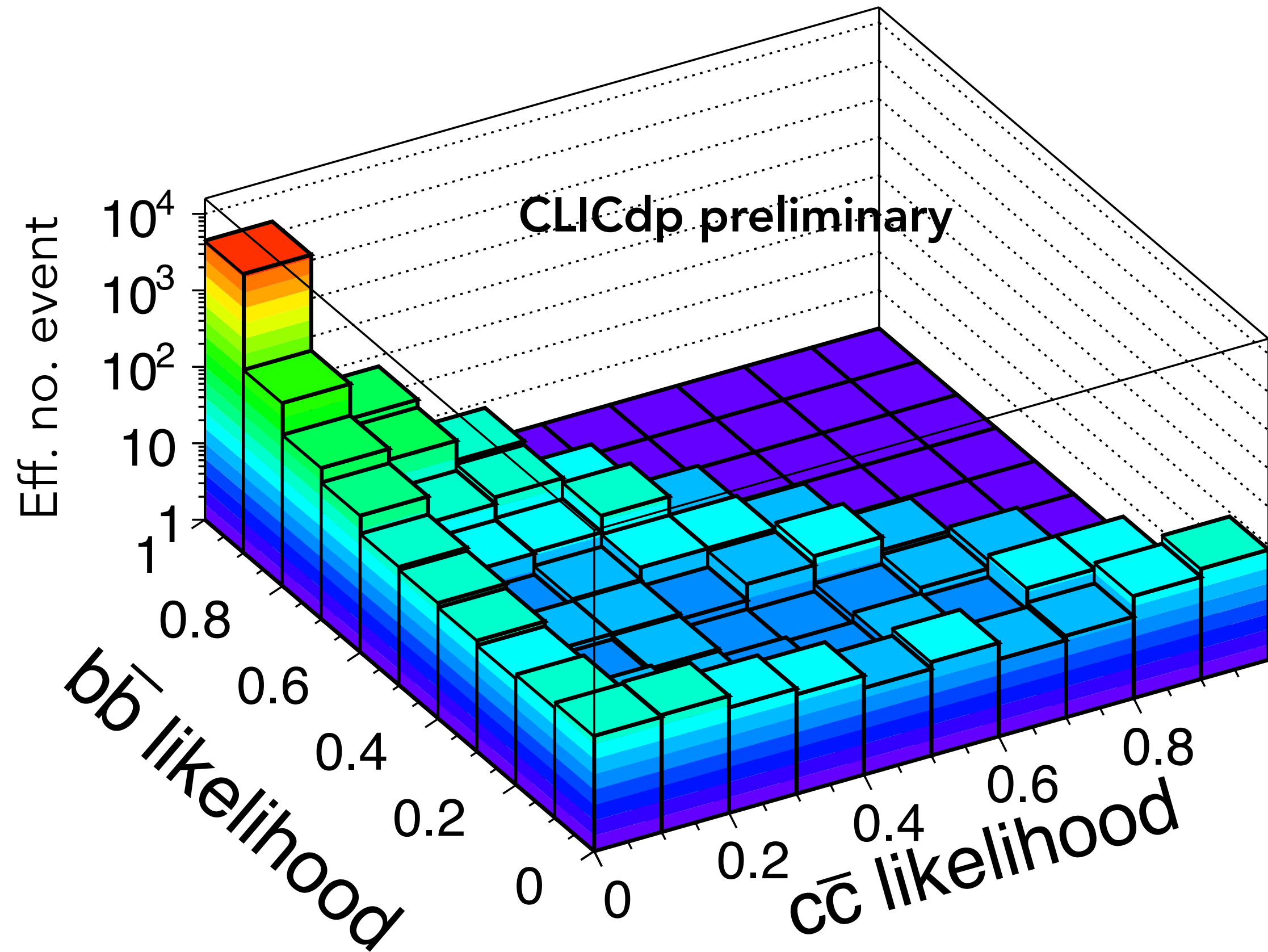
- Iterative de-clustering, parsing through jets
- Inv. mass of subjets: $145 \text{ GeV} \leq m_t \leq 205 \text{ GeV}$
- Incl. two subjets within: $65 \text{ GeV} \leq m_W \leq 95 \text{ GeV}$
- Possible W helicity angle cut



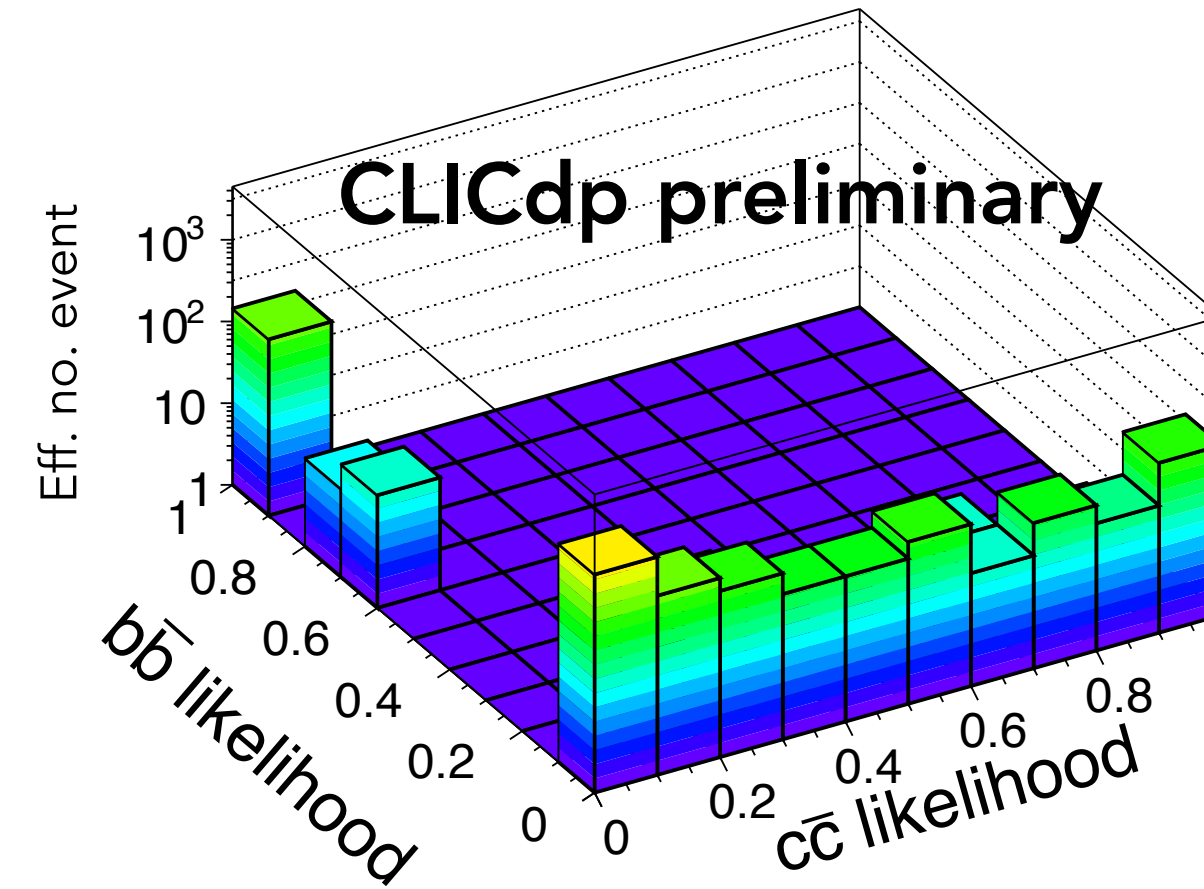
Signal: $tt \rightarrow qqqlv$



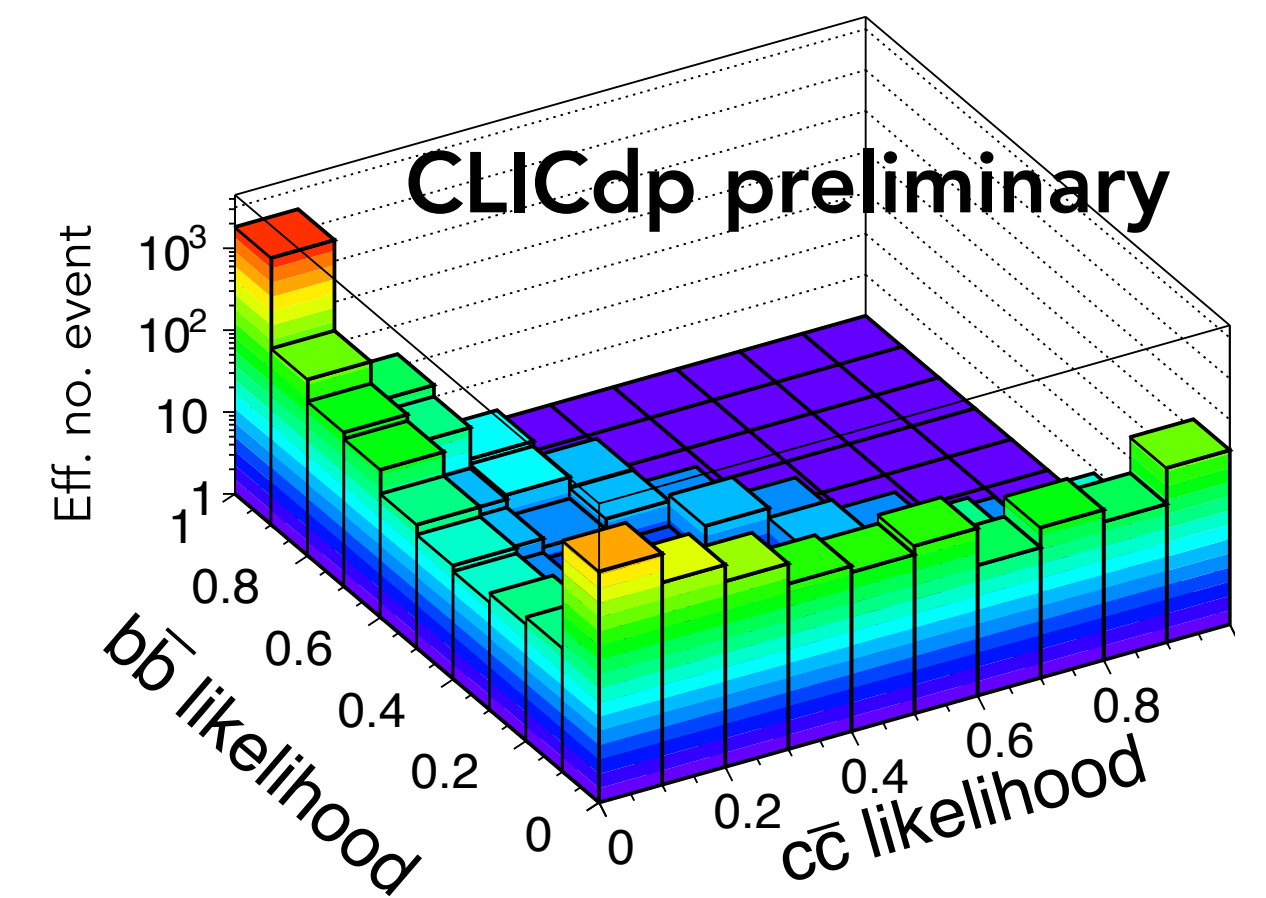
Semi-leptonic **$t\bar{t}$** ($qqqqlv$)



$e^+e^- \rightarrow qq$



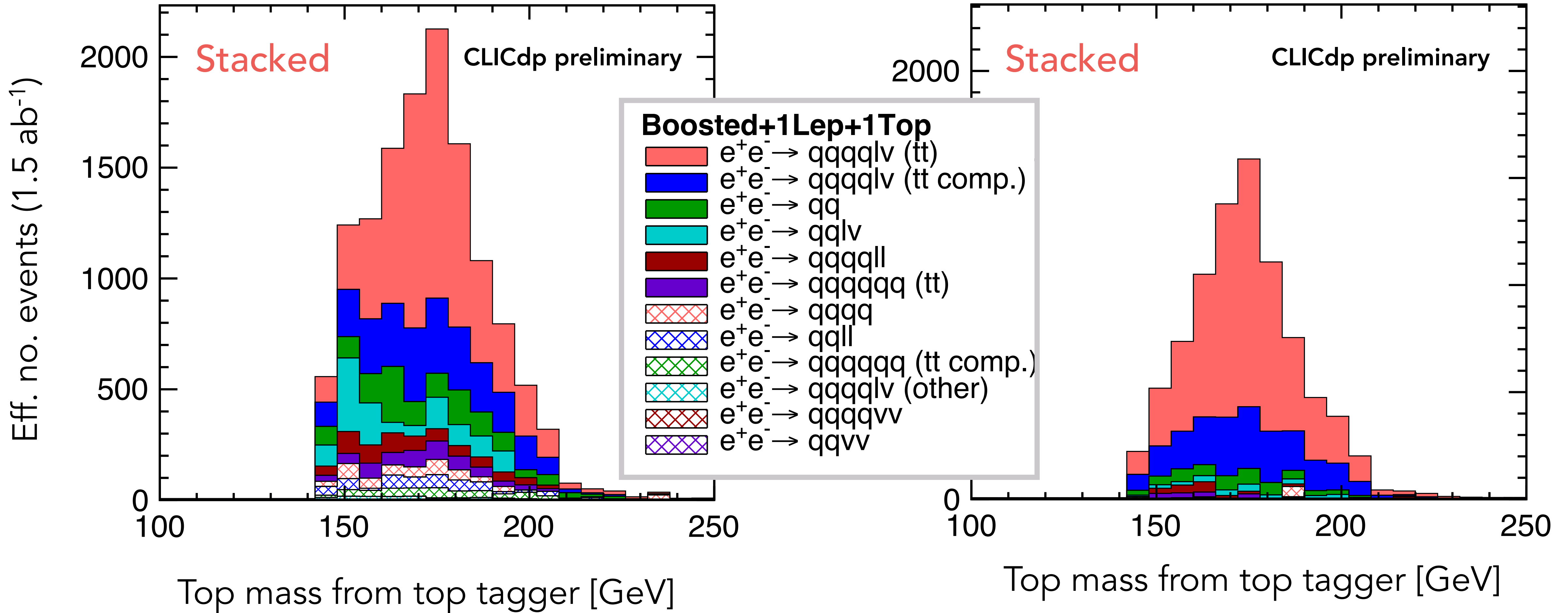
Total Background



- Flavour tagging on two large jets (LCFIPLUS)
- Each jet pair is assigned a bb likelihood and a cc likelihood (arXiv:1608.07538v1)
- Preliminary study promising (e.g. reduce $e^+e^- \rightarrow qq$)
- Next: Apply to non-top tagged part

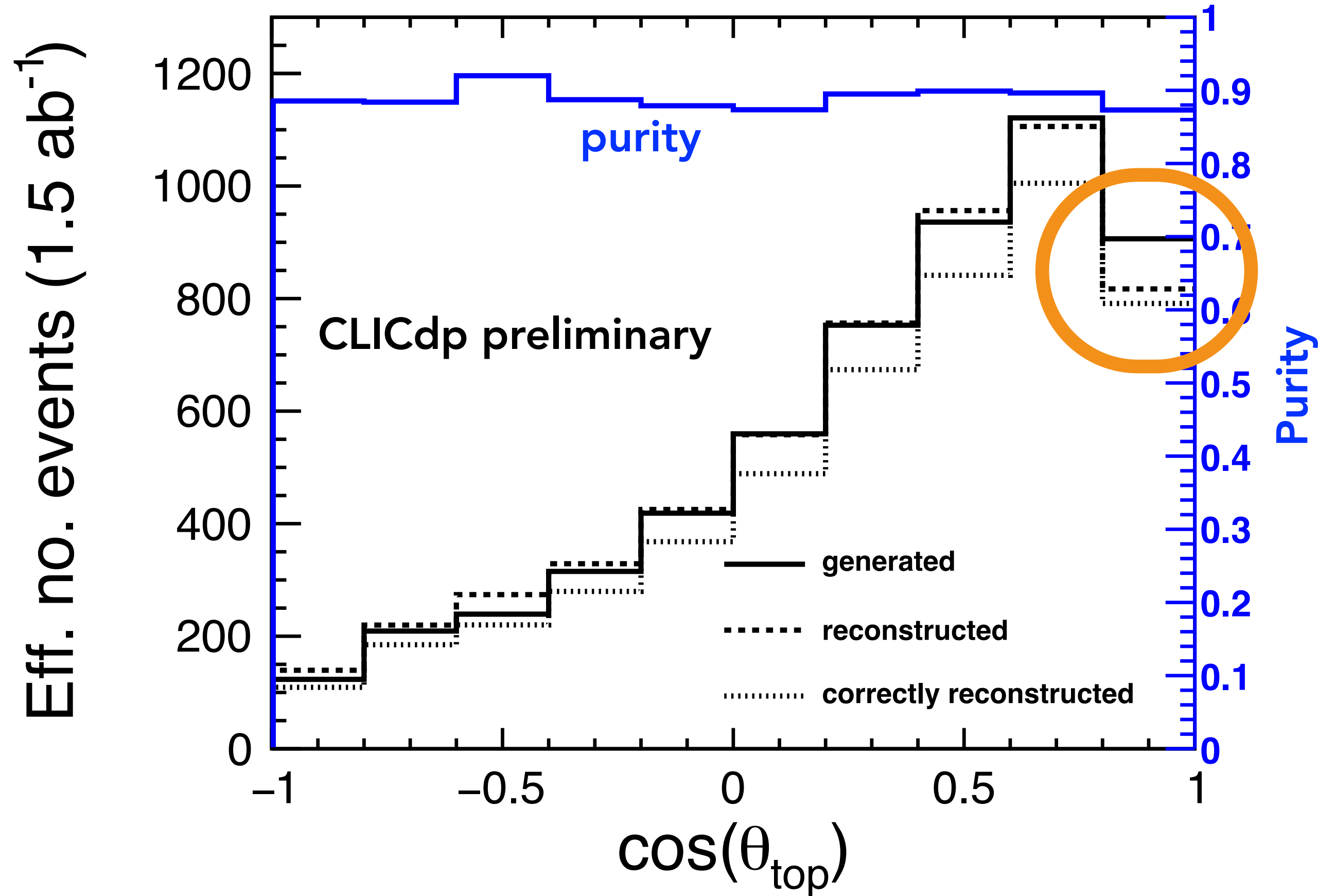
w/o flavour tagging cut

w/ flavour tagging cut



Sample purity

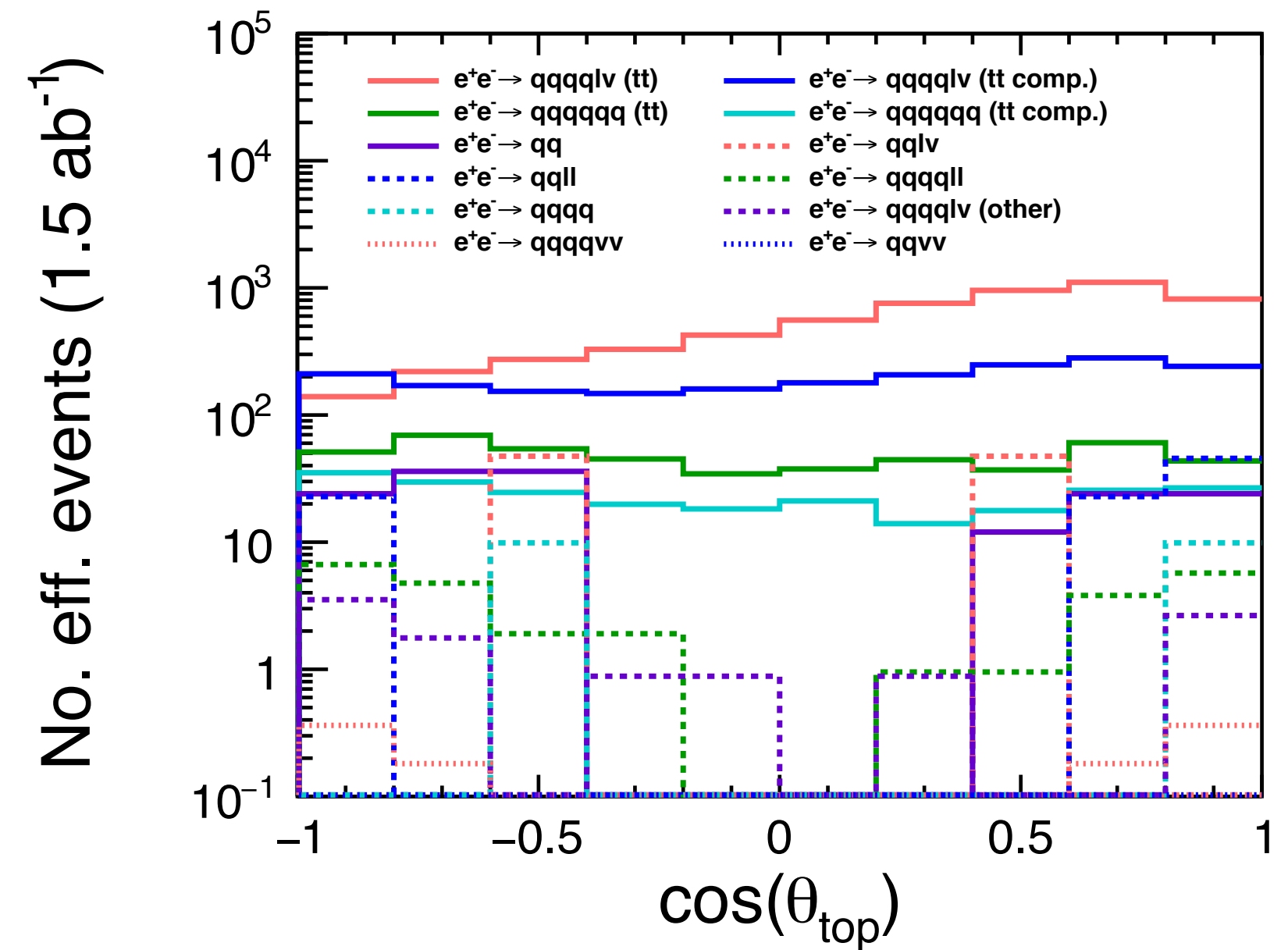
Purity = "reco. in same bin as generated"



Global migration, but high purity!

$$A_{FB}^t = \frac{N(0 < \theta_{top} \leq \pi/2) - N(\pi/2 < \theta_{top} \leq \pi)}{N(0 < \theta_{top} \leq \pi/2) + N(\pi/2 < \theta_{top} \leq \pi)}$$

A_{fb} relative error: ~1-2%



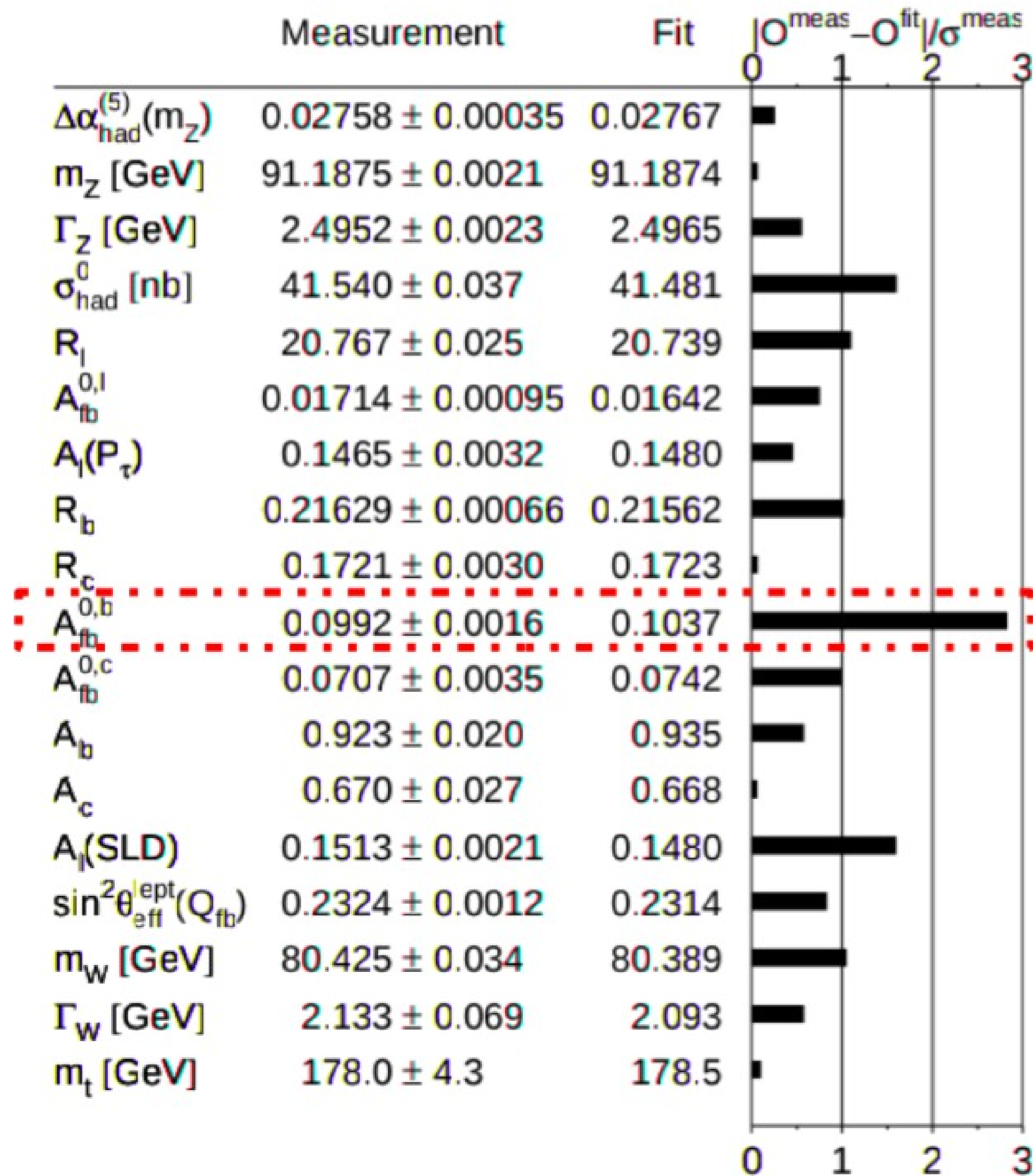
- Investigation of precision on $t\bar{t}$ forward-backward symmetry at 1.4 TeV CLIC (ILD)
- Using semi-leptonic channel - lepton used for charge
- Using boosted techniques
- Pending final optimisation
- Statistical precision on the relative error of $A_{fb} \sim 1-2 \%$

- Interpretation in terms of effective operators, etc.
- Improve top tagger performance
- Analysis steps - move straight cuts to MVA, add “missing” info, etc.



Backup Slides





- The measured value of A_{fb} for b-quarks has the highest tension with SM expectations - An indication of new physics?
- If so, t-asymmetry might show even larger deviation
- Determining top quark couplings through measurement of cross-sections and forward-backward and left-right asymmetries
- Sub-percent precision on anomalous EW couplings yields sensitivity to new physics at scales well beyond the direct reach
- Study of top quark couplings: form-factors or effective operators

Experimentally:

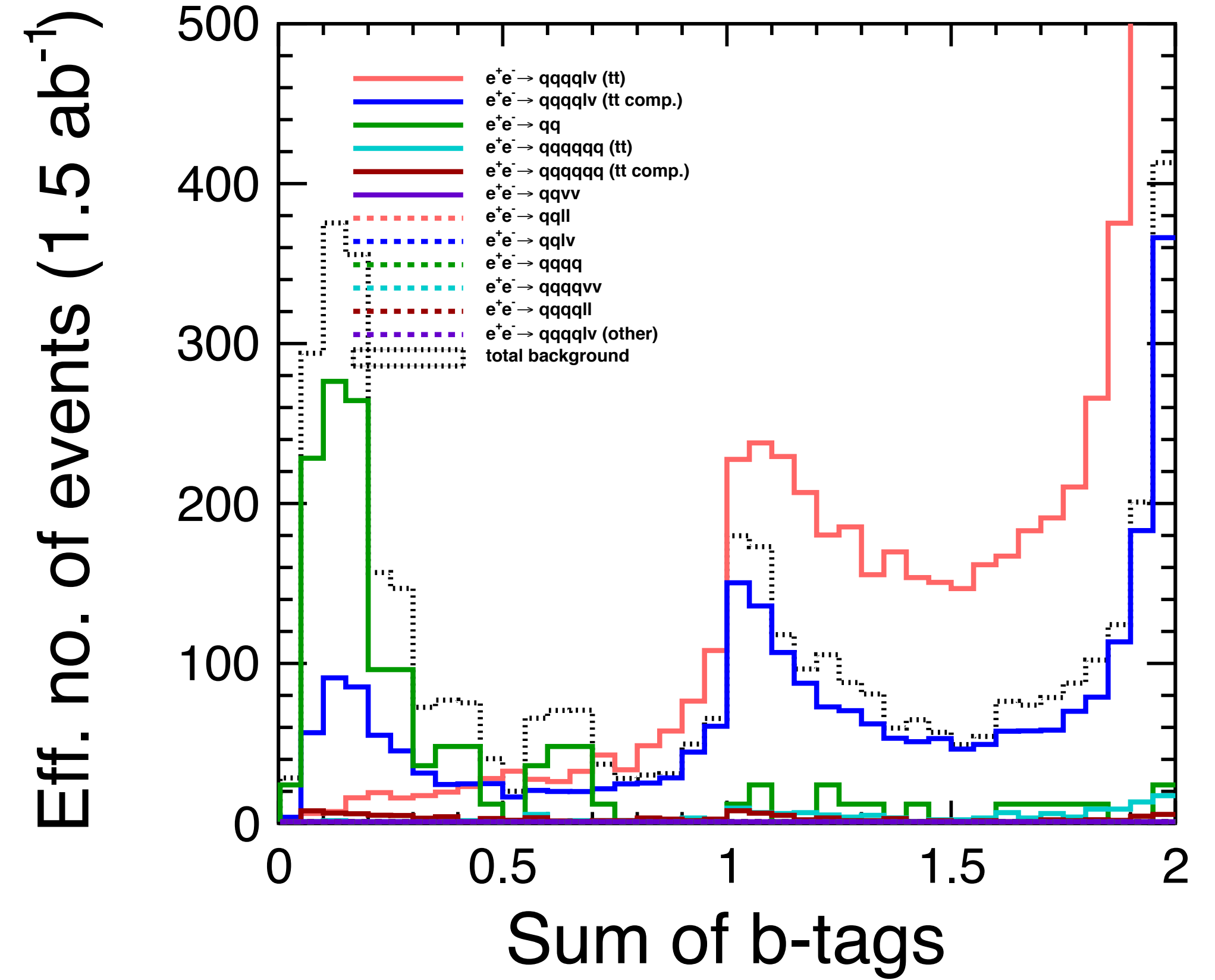
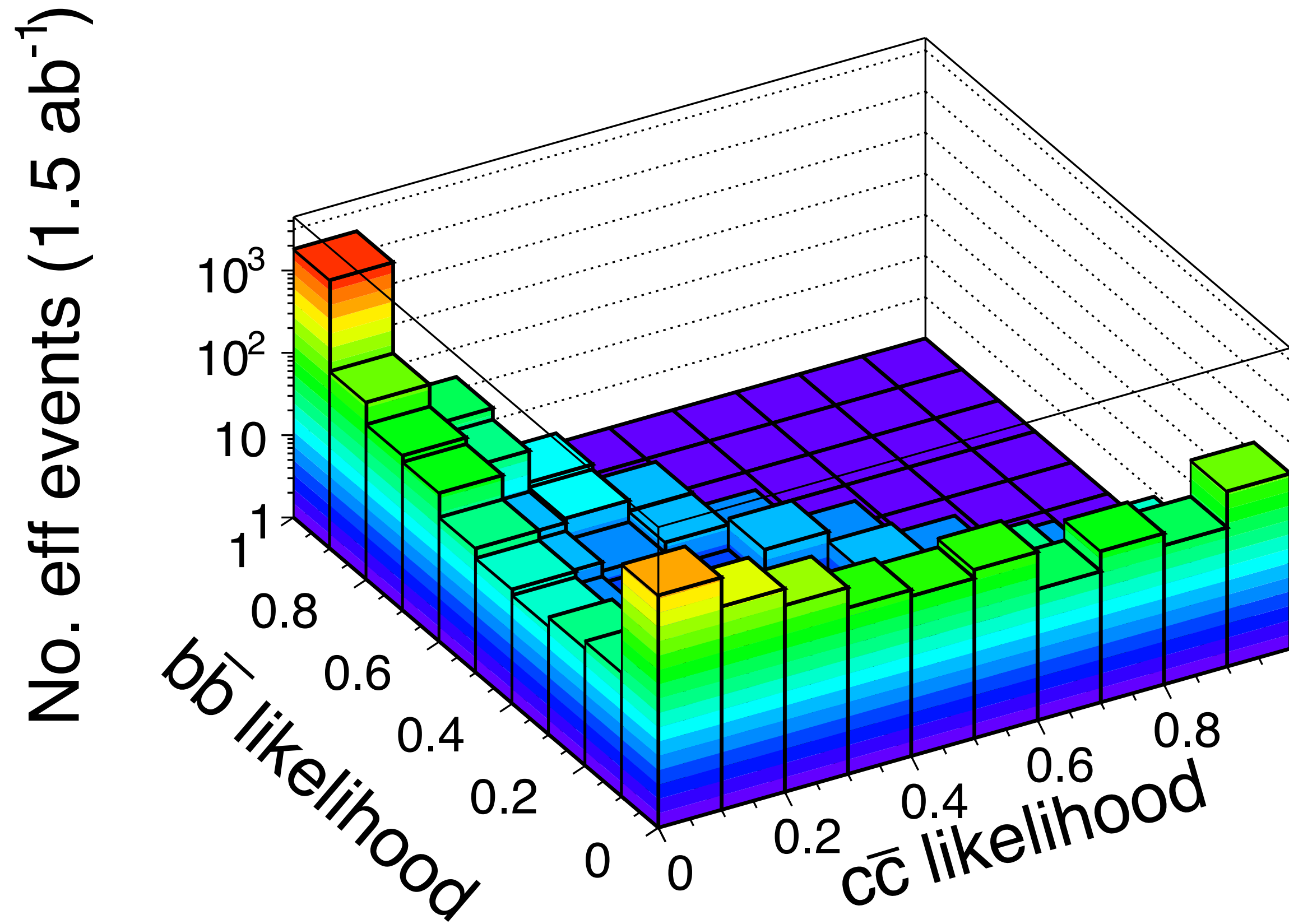
$$A_{FB}^t = \frac{N(0 < \theta_{top} \leq \pi/2) - N(\pi/2 < \theta_{top} \leq \pi)}{N(0 < \theta_{top} \leq \pi/2) + N(\pi/2 < \theta_{top} \leq \pi)}$$

Measure 2 observables for 2 beam polarizations:

$$F_{1A}^{\gamma, \text{SM}} = 0 \text{ always because of the gauge invariance}$$

$$\left. \begin{array}{l} \sigma(+), A_{FB}(+) \\ \sigma(-), A_{FB}(-) \end{array} \right\} \begin{array}{l} (+ = e_R^-) \\ (- = e_L^-) \end{array} \Rightarrow \left\{ \begin{array}{l} F_{1V}^{\gamma} * F_{2V}^{\gamma} \\ F_{1V}^Z, F_{1A}^Z, F_{2V}^Z \end{array} \right\}$$

Total background



1) PFO objects are clustered into jets of size R (large jet) - **any algorithm**

- Iteratively merge 4-vector pairs with closest $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ until $\Delta R < R$

2) Iteratively decluster each resulting jet (reversing each step in the jet clustering) to search for subjets

- Split into two parts, reject softest if
- Declustering continues on the harder object until:

$$\frac{p_T^{\text{subjet}}}{p_T^{\text{jet}}} < \delta_p$$

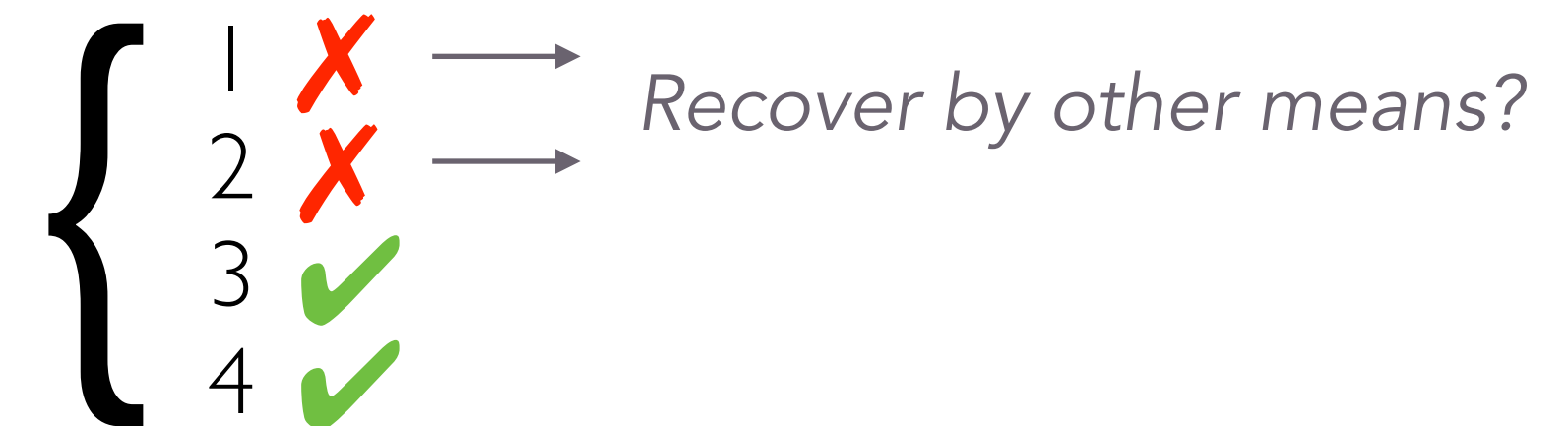
Both subjets are harder than $p_T^{\text{jet}} \cdot \delta_p$ ✓

Both subjets are too close $|\Delta\eta| + |\Delta\phi| < \delta_r$ ✗

Both subjets are softer than $p_T^{\text{jet}} \cdot \delta_p$ ✗

3) If an original jet declusters into two subjets - step 2 is repeated on those subjets

- Results in 1 (original jet), 2, 3, or 4 (additional soft gluon emission) subjets



4) Additional kinematic cuts

✗ = irreducible